University of Reading

Memory properties in Cloud-Resolving Simulations of the Diurnal Cycle of Deep convection

C Daleu[1], *R Plant*[1], *S Woolnough*[1], *A Stirling*[2], *N Harvey*[1]

Presented by **Chimene Daleu**

1- University of Reading

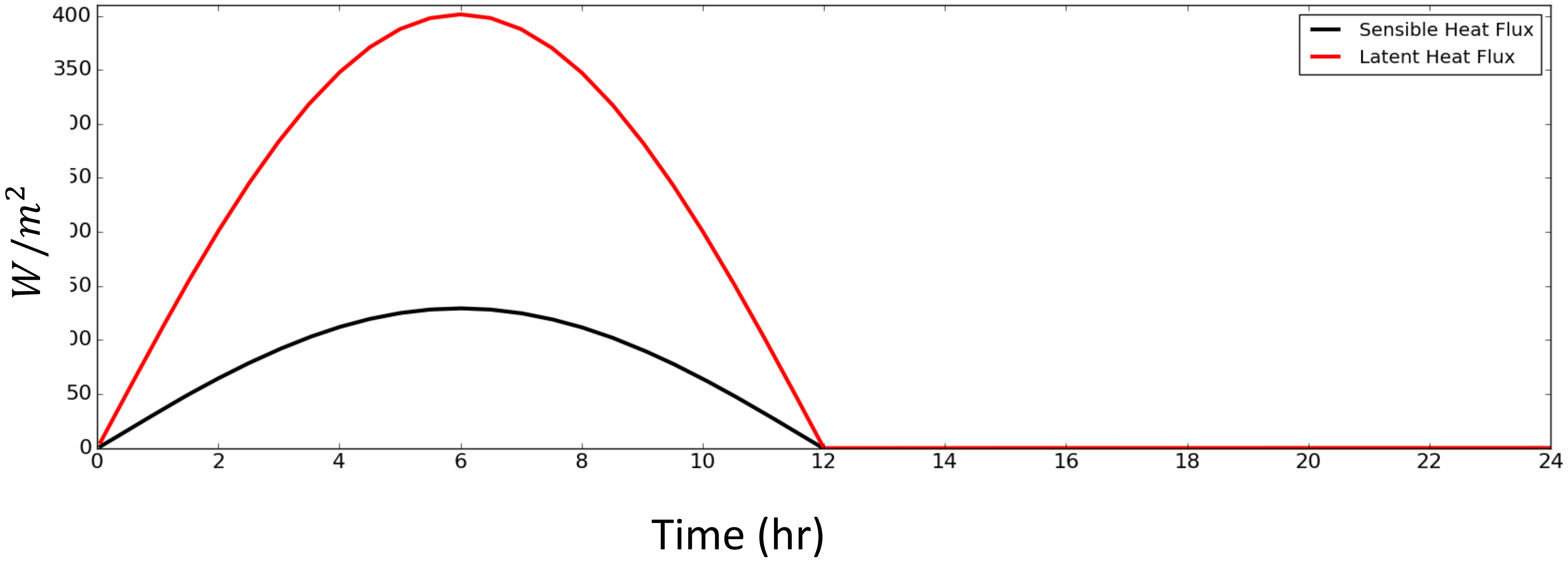
2- UK Met Office

Model description

MONC: the new **M**et **O**ffice **N**ERC **C**loud Model
rewrite of the original Met Office LEM (**L**arge-**E**ddy **M**odel) to include more functionalities.

Model dimensionality	**3D**
Horizontal resolution $\Delta x = \Delta y$	200 m
Domain size	512×512 grid points=100×100 km
Number of vertical levels	99
Vertical resolution	On a stretched grid with more levels near the surface
Model top	20 km
Newtonian damping layer	$\tau = 0.0001, Z_d = 15\ km$ and $H_d = 2.5\ km$
Wind shear imposed	None; u, v relaxed to $0\ m/s$ with $\tau = 2\ h$
Coriolis	Zero
Boundary conditions	Bi-periodic, rigid lid

Setup and forcing are based on the EUROCS case study



Control simulation

Peak SHF =130 w/m^2
Peak LHF= 400 w/m^2
RC=$-\mathbf{1.75}\ K/d$

Sensitivity to the strength of surface forcing

Strongly forced simulation = 1.5*Control

Peak SHF =195 w/m^2
Peak LHF= 600 w/m^2
RC=$-\mathbf{2.625}\ K/d$

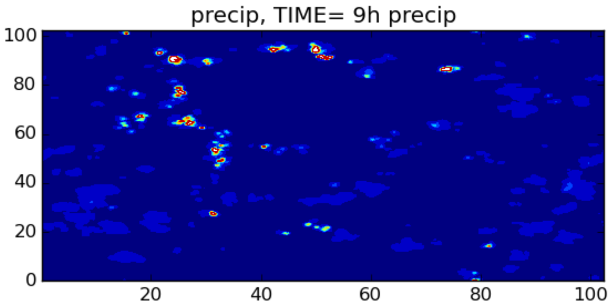
Weakly forced simulation = 0.5*Control

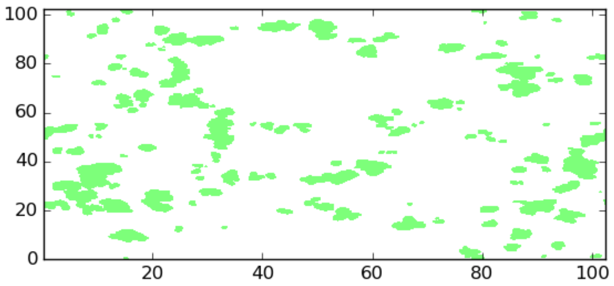
Peak SHF =65 w/m^2
Peak LHF= 200 $\boldsymbol{w/m^2}$
RC=$-\mathbf{0.875}\ K/d$

Same Bowen ratio (~0.3) in all three simulations

Simulations are performed over 10 forcing cycles to ensure **statically significant results** most of the results presented here are the **composites over the last 9 forcing cycles**

Rainfall distribution





Convection is disorganized.

Same behaviour for:

- Weak or strong forcing
- Smaller domain finer resolution
- Larger domain coarser resolution

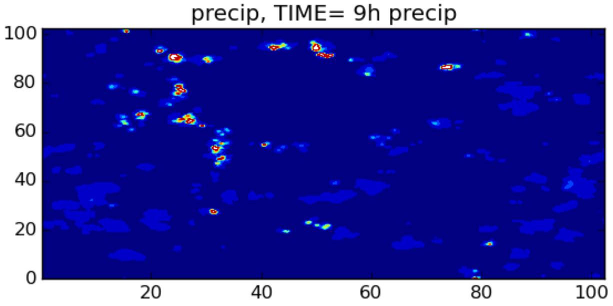
For each 2D surface precipitation field, a grid point (i,j) is masked as rainy if $precip_{i,j} \geq 0.1\ mm/h$ ($50\%\ of\ \overline{< precip >}$ in the control simulation)

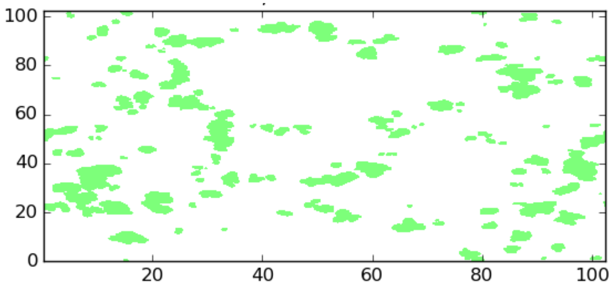
rainy grid points are classified into clusters (*or rainfall events or rain cores*)

Number of rainfall events=N

Area of each event $A_i = n_i \Delta x \Delta y$ with $\Delta x = \Delta y = 200\ m$

Rainfall distribution





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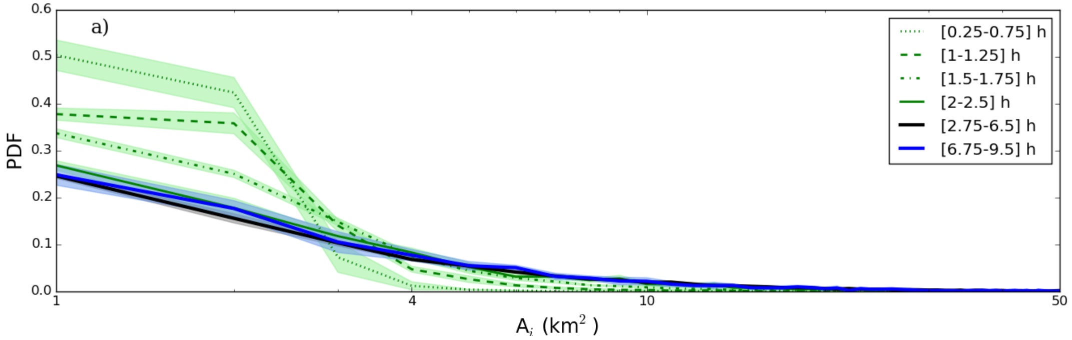


PDF of A_i for t_0 between 0.25-9.5 h
(t_0=for time after triggering of convection)

Rainfall distribution is very broad
with many small rainfall events (Ai < $10\ km^2$) as well as some large ones.

Evolution of rainfall population: Mean rain core radius $\bar{R} = \sqrt{\bar{A}/\pi}$ and σ_{R} (standard deviation of rain core radii)

Evolution of rainfall events

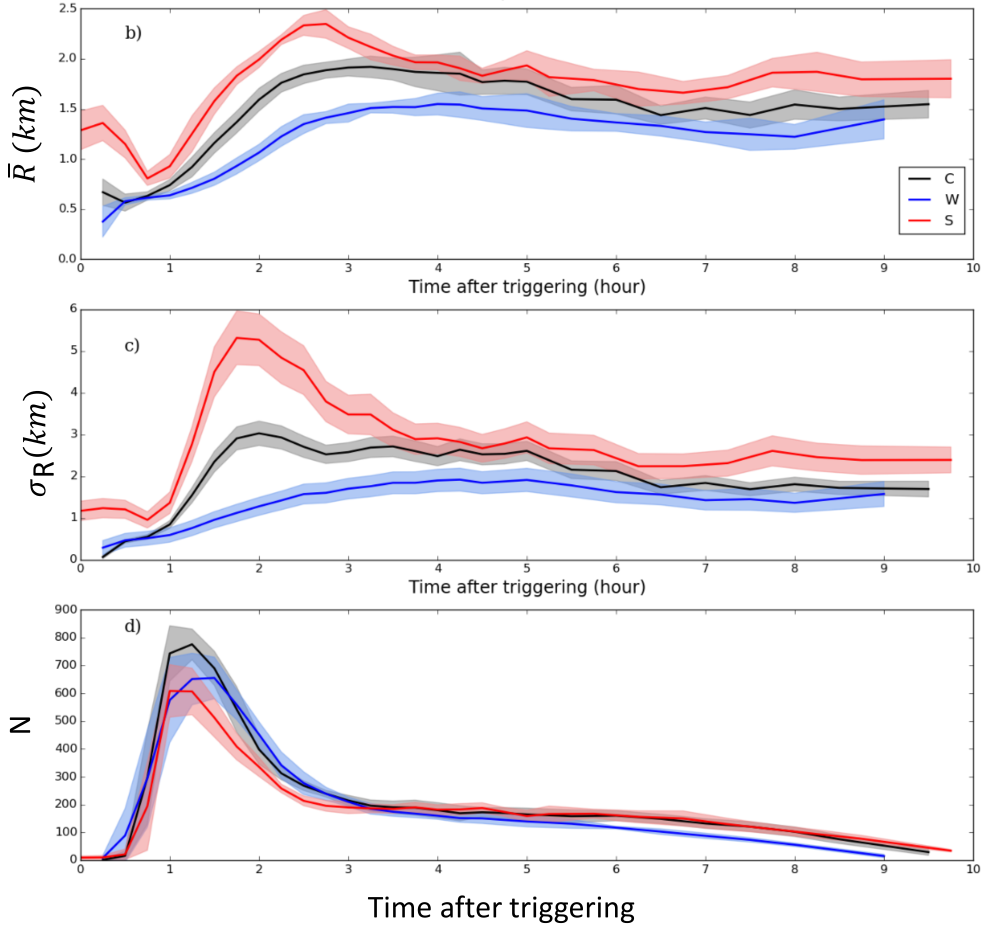
Growing stage:

extends from t_0 =0.75 to 2.75 (strong), 3 (control), and 4 (weak) h

- marked with a gradual growth of $\bar{R}$
- clear dependency on forcing strength
- $\bar{R}$ and σ_{R} increase with the strength of forcing

Oscillatory stage

- $\bar{R}$ oscillates slowly around its equilibrium value
- no clear separations in the evolution of $\bar{R}$ and σ_{R}
- N is decreasing reaches the value of zero when precipitation stops
- $\bar{R}$ does not vary substantially with time (compared to N):
    - *regardless of the strength of forcing* ***the evolution of convection produced by a time-varying surface forcing is mainly dominated by the variability in time on N, with the variability in time on the rainfall characteristics (e.g., $\bar{R}$) being less important.***



Convection depends on its own history?

- Persistence of rainfall events within A: $P[R(A,t_0) \cap R(A,t_0-\Delta t)]$

- The probability of finding persistent rainfall by random chance (for random distributions):
$P^2[R(A,t_0,\Delta t)]=P[R(A,t_0)] \times P[R(A,t_0-\Delta t)]$

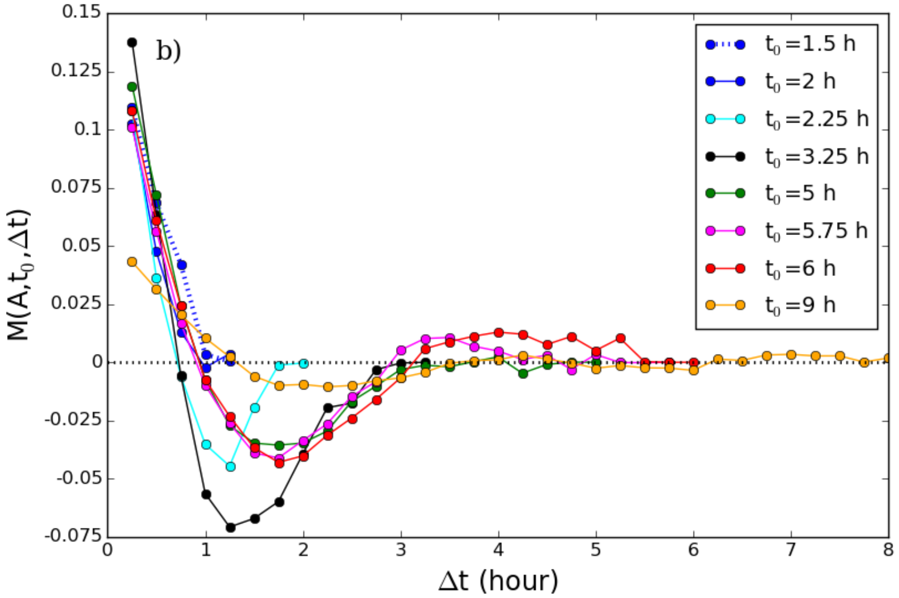
- Convection depends on its history if $P[R(A,t_0) \cap R(A,t_0-\Delta t)] \neq P^2[R(A,t_0,\Delta t)]$

- Memory function: $M(A,t_0,\Delta t)=P[R(A,t_0) \cap R(A,t_0-\Delta t)] - P^2[R(A,t_0,\Delta t)]$

Convection depends on its own history?

$M(A,t_0,\Delta t)=P[R(A,t_0)\cap R(A,t_0-\Delta t)]\ -P^2[R(A,t_0,\Delta t)]$

example plot for A=$4\times 4km^2$ →

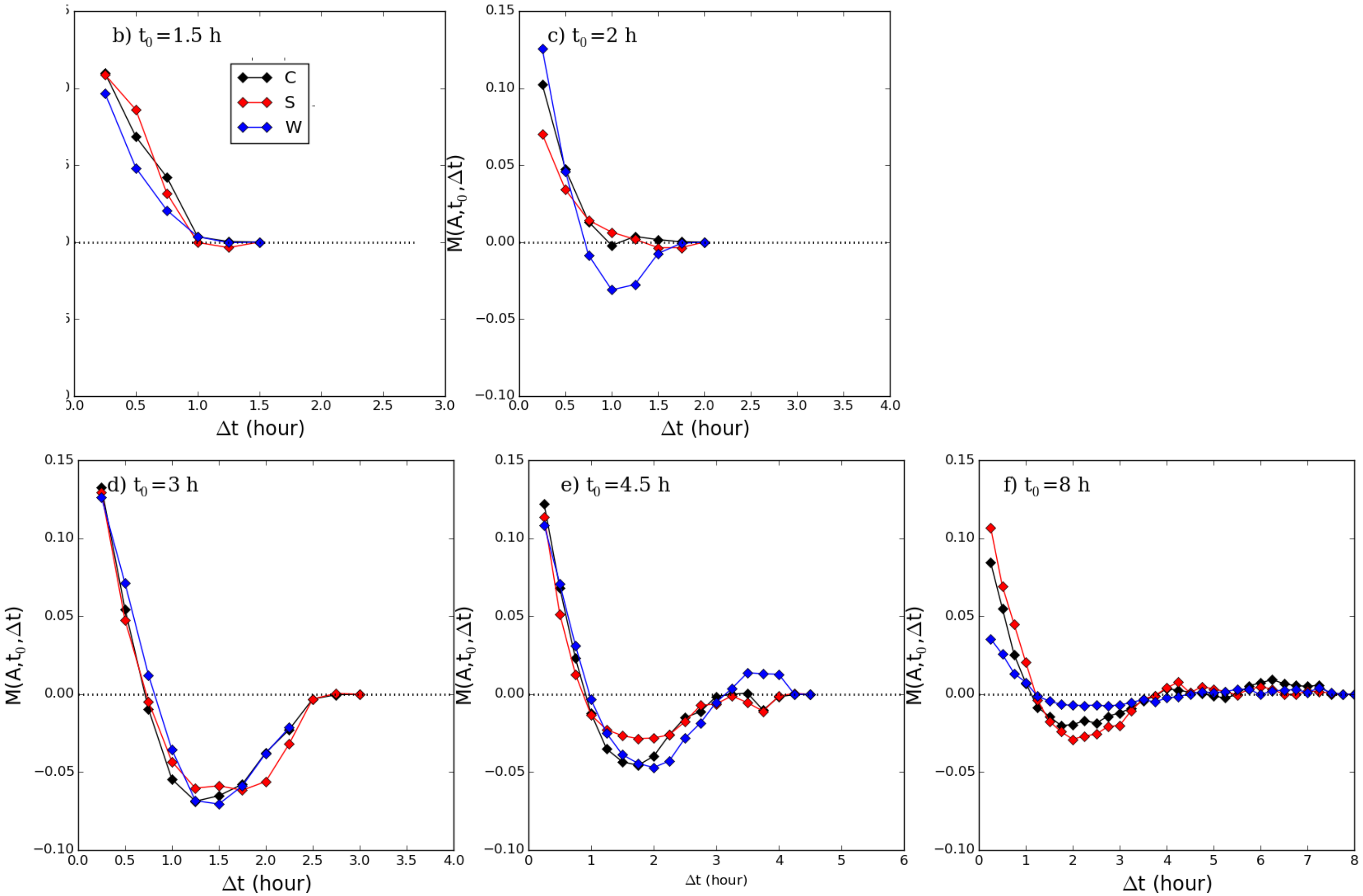


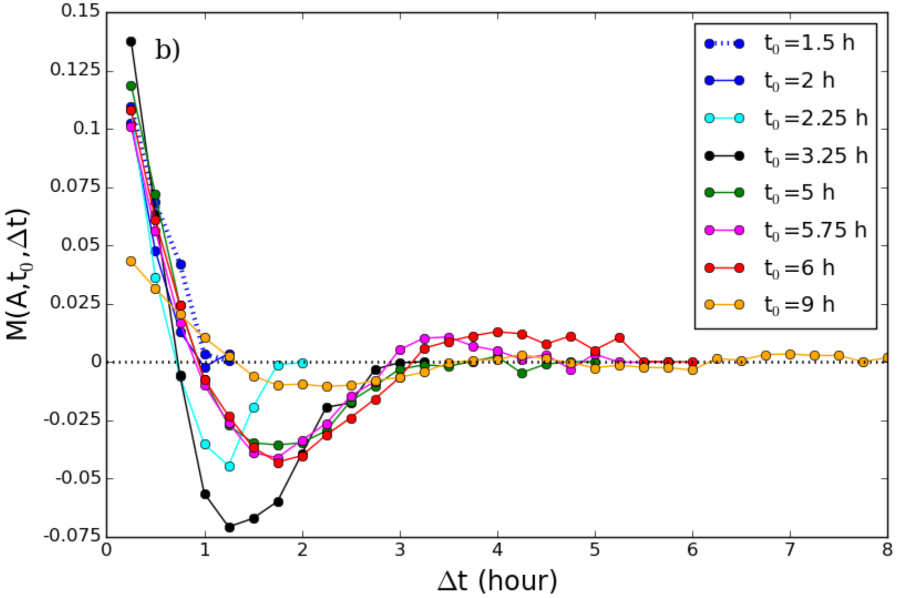
- Positive (negative) M→ convection at $t_0\ -\Delta t$ acts to enhance (suppress) convective activity at t_0.
- The minimum value of M represents the strongest suppressed state of conv
- Recovery time of convection→ transition from the strongest suppressed state to the state expected given no memory (the zero line)
- In the early stage of the diurnal cycle: persistence of the newly developing convection→ maintained for about an hour
- From t_0 =2.25h indication of local suppression:
  - initial persistence of convection is followed by a suppression for a further 1 h (at $t_0\ = 2.25$h) to 2 h (from $t_0\ = 3.25$h)
- For t_0 between 5.75-7.25 h: a further enhancement of convection for Δt = 3 -5 hours

$M[R(A,t_0,\Delta t)]$: is not sensitive to domain size and/or horizontal resolution
sensitives to the strength of the forcing?

For A=$4 \times 4km^2$

$M[R(A,t_0,\Delta t)]$: Sensitives to the strength of the forcing?

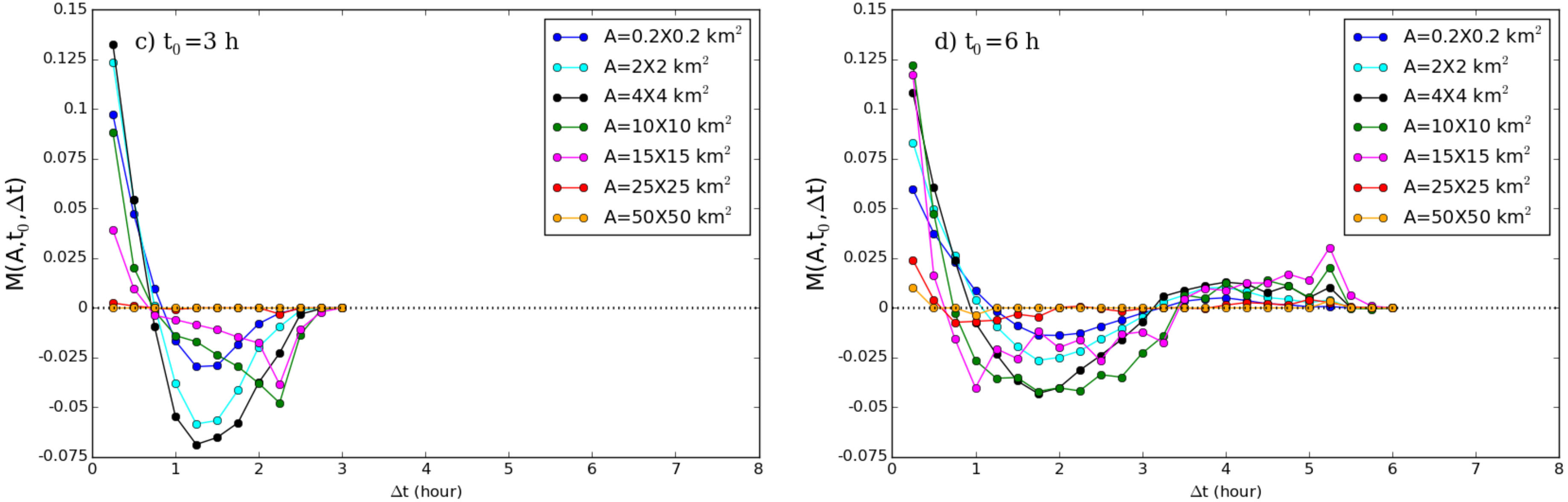




- Control and Strongly forced simulations: **qualitatively similar** evolution of the memory function

- Weakly forced simulation: M shows few differences:
  - The negative memory develops a little earlier
  - The appearance of a secondary enhancement of precipitation occurs at t_0=4.5h (compared to t_0= 5.75h in **C** and **S**)

$M[R(A, t_0, \Delta t)]$: Sensitivity to the area; A within which convection is evaluated?



Regardless of the strength of the forcing

- The shapes of M for A<$10 \times 10km^2$ are qualitatively similar
  - Control, weakly and strongly simulations, t**he strongest memory is obtained for areas between** $4 \times 4km^2$ and $10 \times 10km^2$(grey-zone scales)
- Different behaviour for A>$10 \times 10km^2$
  - **E.g.,** for A=15 × 15 km^2 convection occurring at t_0=3h starts to recover from Δt =2.5h (compared to $\Delta t = 1$.5h for A=$4 \times 4km^2$)
- For A=25×25 km^2: the impact of previous convection is reduced substantially
- For A>25×25 km^2 (e.g., 50×50 km^2): convective memory is negligible

Memory attributed to the thermodynamic variabilities at night time

Surface fluxes are off between hours 12-24
No clouds and convection between hours 15-24

Thermodynamic fluctuations 12 hours after a decaying day time convective events.

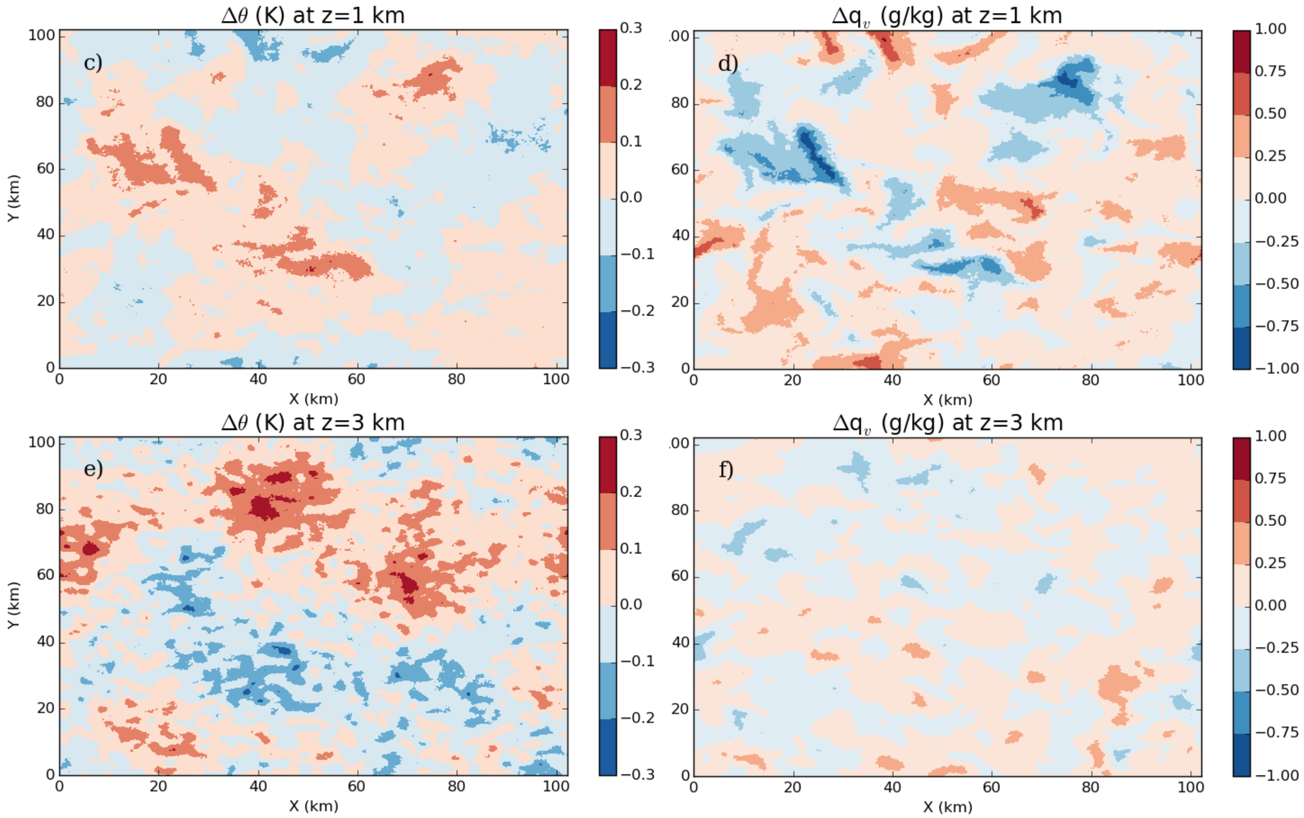
- evidence of an anti-correlation between θ and q_v

- **Do they influence the evolution of convection on the next diurnal cycle**?

Homogenization $\dfrac{\partial \chi^k_{i,j}}{\partial t} = -\dfrac{1}{\tau}\left(\chi^k_{i,j} - \bar{\chi}^k\right)$

is applied

- to θ and q_v
- at all vertical levels
- between hours 15-24



***** Following **homogenization**

- $\overline{< precip >}$ (intensity of convection) is reduced by about 10%, now **0.18mm/d** (compared to **0.2mm/d** in the control simulation)
  →only 10% reduction because the amplitudes of θ' and q_v' **are smaller**

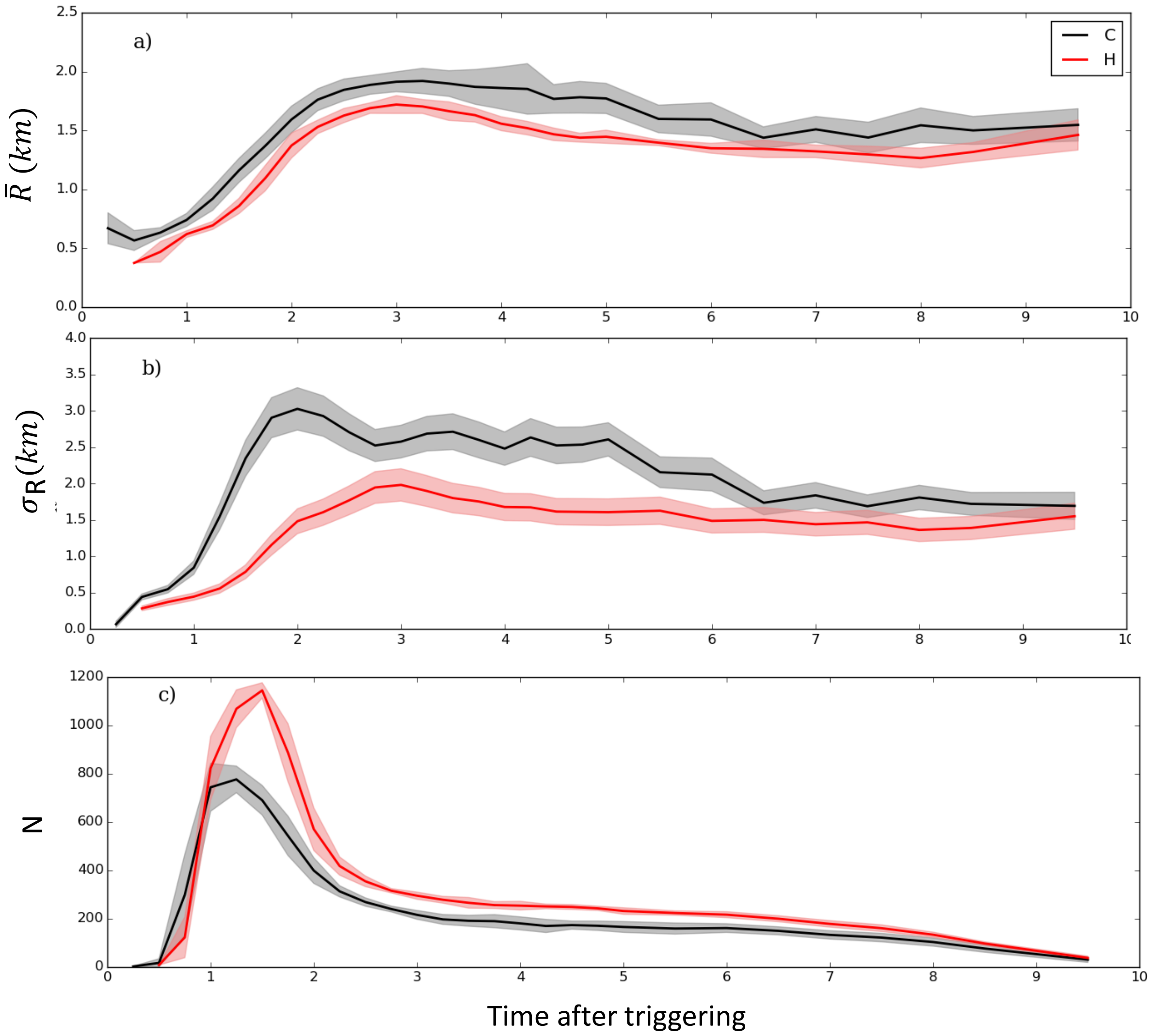
- Even though thermodynamic fluctuations have a little impact on the timing and intensity of convection
- They do have a significant impact on the evolution and distribution of rainfall events

Clear separations in the evolution of rainfall events

Following homogenization

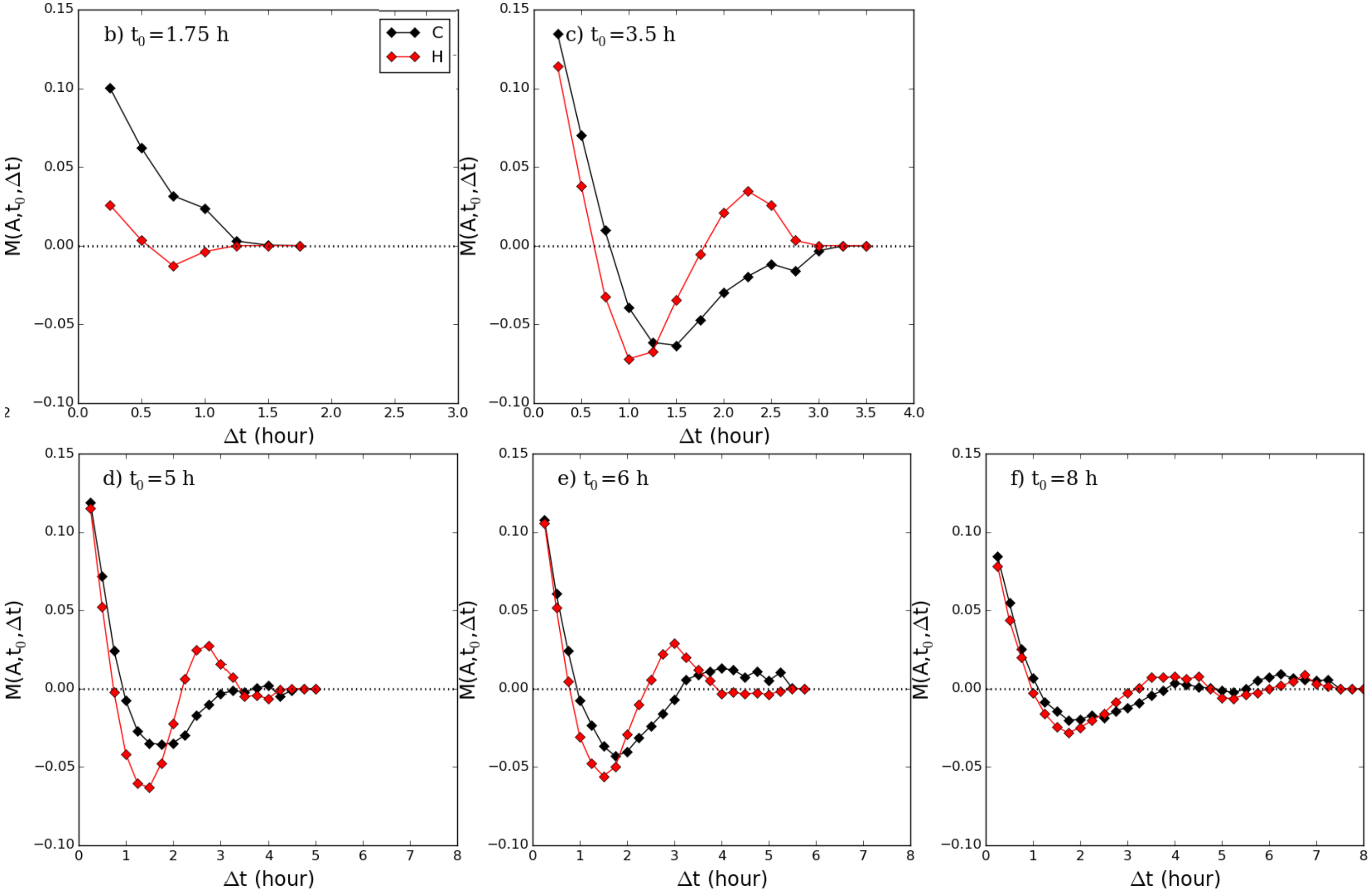
- Cloud-size distribution is narrower and more numerous and smaller rainfall events occurs during the day
- N peaks at t_0 =1.5 hours and is increased by about 350 (about 50% With respect to the control sim)

- Knowing that convection intensity is reduced by 10%, N is increased by 50% and that the total mass flux is almost unchanged
    - Rainfall events are less intense (in mass flux and rainfall amount) than those generated in the control simulation.



For A=4 × $4km^2$

Sensitivity to the strength of the forcing?



Following homogenization perturbations

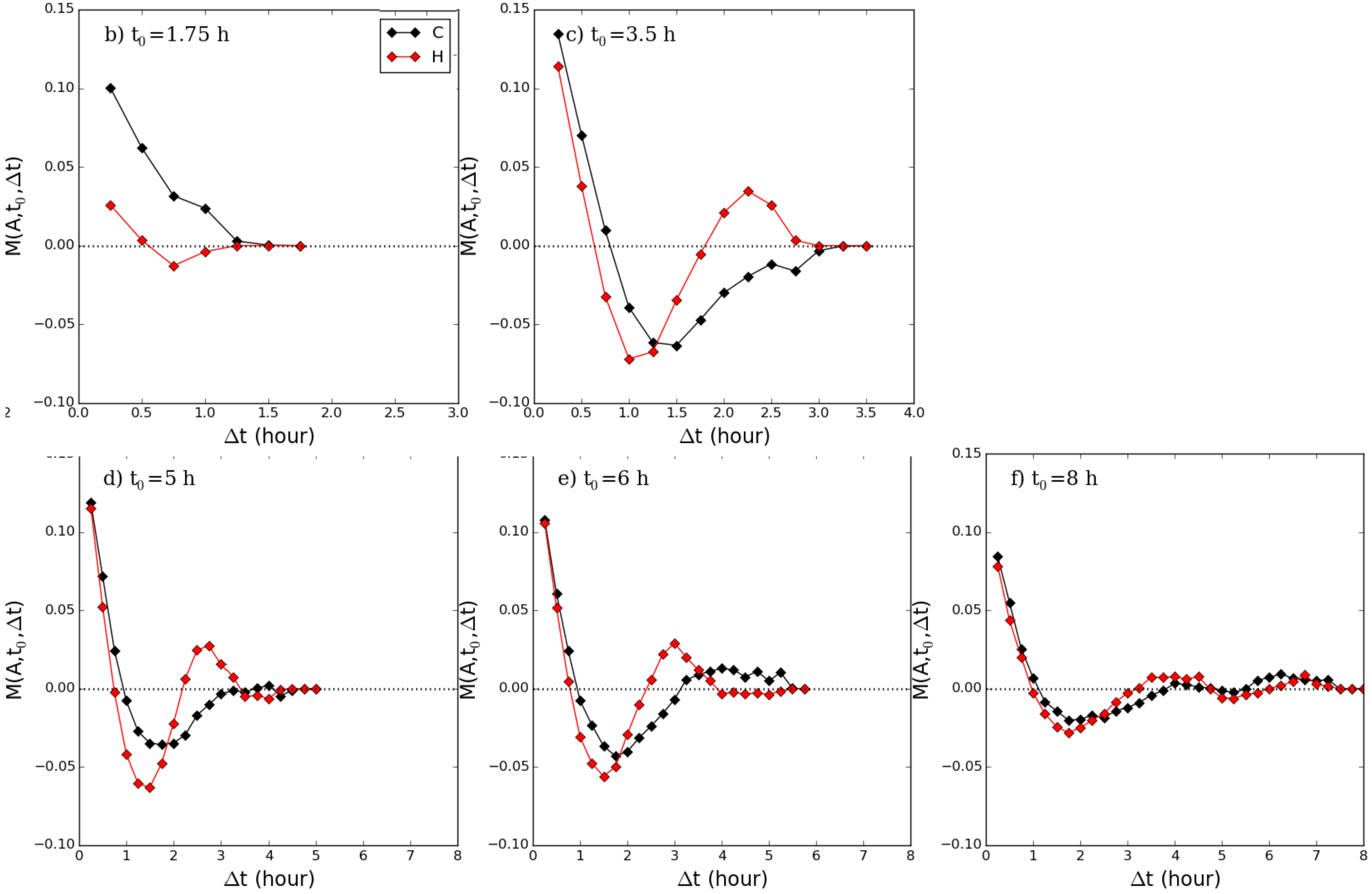
- The strongest memory is obtained for A between $4 \times 4km^2$ and $10 \times 10km^2$
- The rainfall events are less intense, and somewhat less persistent.
- The negative memory and secondary enhancement (more stronger) develop earlier
- The local atmosphere also recovers more rapidly: up to 1.5 hours earlier for convection produced between t_0 = 2.5 and 6.5 hours

Where does the memory attributed to θ' and q_v' resides?

- Homogenization restricted to 4-20 km: *the effects are **almost zero***
- Homogenization restricted 0-4km: *greatest impact*

For A=4 × $4km^2$

Sensitivity to the strength of the forcing?



Following homogenization perturbations

- the more numerous rainfall events result in larger $P[R(A,t_0)]$ during the first 8 hours after triggering
- The strongest memory is obtained for A between $4 \times 4km^2$ and $10 \times 10km^2$
- The rainfall events are less intense, and somewhat less persistent and the negative memory and secondary enhancement develop earlier
- The local atmosphere also recovers more rapidly: up to 1.5 hours earlier for convection produced between t_0 = 2.5 and 6.5 hours

Where does the memory attributed to θ' and q_v' resides?

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Summaries

- This study focuses on the diurnal cycle of disorganized convection under very idealized forcing conditions

- There is no memory for grid spacings coarser than 25 km (e.g., 50 km)
- The strongest memory is obtained at grey-zone scale (4-10km) and has three phases:
  - The first phase: enhanced precipitation where it was already precipitating
    (This first phase, is in principle already represented by some memory mechanisms included in some convective parameterization schemes [e.g., Willett and Whitall , 2017].)
  - The second phase: suppressed precipitation where it was previously enhanced and subsequently
  - The third phase: a secondary enhancement of precipitation where it was previously suppressed
    - These second and third phases of the memory function are not yet directly represented in conv parameterization schemes.
      (Future studies are planned to assess the ability of current convective parameterizations in capturing such effects.)

- Thermodynamic fluctuations generated about 12 hours after a decaying convective events have
  - A little impact on the timing and intensity of convection
  - A significant impact of the evolution of rainfall events
    - N decreases (up to 50% reduction), R increases, and rainfall distribution is wider
    - Rainfall events are more intense, thus decay and recover more slowly
  - Convective memory attributed to thermodynamic fluctuations resides in the lowest 4 km.

Limitations: for more realistic simulations the memory properties of convection may be modified

- for mesoscale organized convection or
- by the presence of an interactive land-surface; vertical wind shear; or cloud-radiative interactions.

Future studies are planned to investigated the impact of prescribed heterogeneous surface conditions on convective memory.

Thanks

Questions?